# Office of Naval Research Graduate Traineeship Award in Ocean Acoustics for Ankita Deepak Jain

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Grant Number: N00014-09-1-0679

## LONG-TERM GOALS

The long-term goal of this research is to develop a unified theory and model for ocean reverberation dependent on seafloor parameters such as density, compressibility and coherence volume. We aim at using the model to invert for these parameters and obtain accurate estimates by calibrating modeled returns with data collected during past Ocean Acoustic Waveguide Remote Sensing (OAWRS) experiments.

We also aim at developing a method for probing the ocean and ocean sediment at larger depth for imaging submerged objects at high resolution. We aim to use nonlinear scattering of sound in the presence of inhomogeneities to obtain high resolution images at high penetration depth. Through the developed theory, we can tackle the problem of high attenuation of acoustic field at high frequencies in ocean sediment, and the low resolution of low frequencies on the other hand.

Another goal of this research is to model biological clutter and attenuation in the continental shelf environments of the ocean. Acoustic clutter is the primary problem encountered by active sonar systems operating in these environments, and clutter characterization will help distinguish biological clutter from seafloor reverberation and intended targets.

## OBJECTIVES

(1) Formulating a unified theory and developing a model of reverberation from ocean seafloor.
(2) Developing a method for probing the ocean and ocean sediment based on a nonlinear theory developed for the scattering of sound in the presence of inhomogeneities.
(3) Modeling and characterization of biological clutter in continental shelf environments.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE **2010** | 2. REPORT TYPE | 3. DATES COVERED **00-00-2010 to 00-00-2010** |

4. TITLE AND SUBTITLE
**Office of Naval Research Graduate Traineeship Award in Ocean Acoustics for Ankita Deepak Jain**

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**Massachusetts Institute of Technology,77 Massachusetts Avenue, Room 5-212,Cambridge,MA,02139**

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT **unclassified** | b. ABSTRACT **unclassified** | c. THIS PAGE **unclassified** | **Same as Report (SAR)** | **4** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

## APPROACH

Using the seafloor reverberation measurements from Ocean Acoustic Waveguide Remote Sensing (OAWRS) experiments in 2003 and 2006, we formulate a unified reverberation theory for the different ranges, frequencies and grazing angles used in these experiments [2]. The different frequency bands provide a wide range of low frequency measurements to verify and potentially improve the existing low- frequency sea-bottom reverberation models. The matched filter is applied in many remote sensing systems to provide high resolution imaging. We use matched filter and beamforming to map the scattered returns in range and bearing respectively, to obtain wide-area reverberation maps. We develop a theory for the statistical moments of the broadband matched filtered returns simultaneously scattered from random distribution of scatterers [3].

Detection of buried objects in ocean sediments is hindered by the following problems: (i) high frequency, high resolution images lead to high attenuation of acoustic field in ocean sediments, (ii) low frequencies lead to much lower target strengths and poorer resolution. Through a developed theory on nonlinear scattering of sound, we tackle the above problems. The use of two incident waves differing slightly in frequency results in sum and difference frequency waves that, by appropriate choice of the incident frequencies, can achieve both higher penetration into sediment and better resolution. For objects with different geometries and acoustic properties we have shown that the the physics of the response are different [1]. Exploiting these differences is key in detecting and discriminating submerged and buried objects.

During the past OAWRS experiments in 2001, 2003 and 2006, we demonstrated that fish schools are the dominant cause of clutter in typical continental shelf environments [4-6]. In order to characterize the spatial and temporal behavior of biological clutter, we model schools of randomly distributed fish based on the inverted parameters of fish obtained from the data collected during the these experiments. We explore the dependence of scattered returns from fish shoals on frequency and bandwidth of acoustic source, depth distribution of fish in the water column, fish population density, etc. This model will then be extended to simulate wide-area movies, similar to those developed from collected data in the past [4, 5], showing temporal and spatial evolution of vast oceanic fish shoals.

## WORK COMPLETED

The model for scattering from random inhomogeneities in range-dependent ocean environments has been improved to include the matched filter. By applying the matched filter theory from first principles, the scattered intensity from the entire ocean seafloor is mapped in range, avoiding the need to artificially break up the seafloor into patches of size of the resolution footprint. The fluctuations in the sound speed caused by internal waves, eddies, and turbulence are taken into account by performing several Monte-Carlo simulations. We derive the statistical moments of the scattered field from the seafloor and find that the second moment dominates the received intensity. The model is then calibrated with data acquired during the past OAWRS experiments, and is used to estimate seafloor parameters such as density and compressibility and medium coherence volume.

A theory for nonlinear scattering of sound in the presence of inhomogeneities has been derived and will be used in detection of submerged targets at higher resolution and depth. From the equations of mass conservation, momentum conservation and state, the second-order nonlinear wave equation in the presence of inhomogeneities was derived, and a general solution was obtained in the form of a volume integral, which was evaluated for a number of canonical cases.

The use of two incident waves results in sum and difference frequency waves that by appropriate choice of the incident frequencies can achieve both higher penetration into sediment and better resolution. For objects with different geometries and acoustic properties we have shown that the contribution of each mechanism, and consequently the physics of the response are different. We utilize these differences in imaging and detecting submerged and buried objects.

## IMPACT/APPLICATIONS

- A unified, range-dependent, broadband ocean reverberation model and calibration of modeled returns from seafloor sediments with past data will provide a tool for accurately estimating seafloor properties. This model helps distinguish between fluctuating returns due to clutter and statistically stationary seafloor reverberation.

- We have developed a theory for nonlinear scattering of sound in the presence of an inhomogeneity insonified by two plane waves at slightly different frequency, and have explained the mechanisms through which sum and difference frequency waves are generated. Our theory can be used in detection and discrimination of objects buried in seafloor sediments, by simultaneously using the high penetration of the incident low frequency waves and the high resolution of the sum frequency wave.

## REFERENCES

[1] Hadi T. Nia, Purnima Ratilal, Nicholas C. Makris, "Nonlinear Scattering of Sound in the Presence of Inhomogeneities," to be submitted to Phys. Rev. E.

[2] Ameya Galinde, Ninos Donabed, Mark Andrews, Sunwoong Lee, Nicholas C. Makris and Purnima Ratilal, "Range-dependent Waveguide Scattering Model Calibrated for Bottom Reverberation in Continental Shelf Environments" J. Acoust. Soc. Am 123, 1270-1281 (2008).

[3] Mark Andrews, Zheng Gong, and Purnima Ratilal, “High-resolution population density imaging of random scatterers with the matched filtered scattered field variance”, J. Acoust. Soc. Am. 126 1057-1068 (2009).

[4] Nicholas C. Makris, Purnima Ratilal, Srinivasan Jagannathan, Zheng Gong, Mark Andrews, Ioannis Bertsatos, Olav Rune Godoe, Redwood W. Nero, J. Michael Jech, "Critical Population Density Triggers Rapid Formation of Vast Oceanic Fish Shoals", Science, Vol. 323, No. 5922, 1734-1737 (2009).

[5] Nicholas C. Makris, Purnima Ratilal, Deanelle T. Symonds, Srinivasan Jagannathan, Sunwoong Lee and Redwood W. Nero, “Fish Population and Behavior Revealed by Instantaneous Continental Shelf-Scale Imaging,” Science, 311, 660-663 (2006).

[6] Purnima Ratilal et al and N.C. Makris, “Long range remote imaging of the continental shelf environment: The Acoustic Clutter Reconnaissance Experiment 2001 Experiment,” J. Acoust. Soc. Am. 117, 1977-1998 (2005).